Determining Planetary Boundary Layer Heights with Ground-based Lidar and Wind profiler on Short Spatial and Temporal Scales

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PBLH Intercomparison Locations

UMBC
- 532 nm Elastic Lidar (ELF)

Howard Univ. Beltsville Research Campus
- SigmaSpace MicroPulse Lidar(MPL)
- Vaisala Ceilometer (CL51)
- Radiosondes
- 915-MHz Wind Profiler

Edgewood-Aberdeen Proving Ground
- SigmaSpace MPL
- Radiosondes

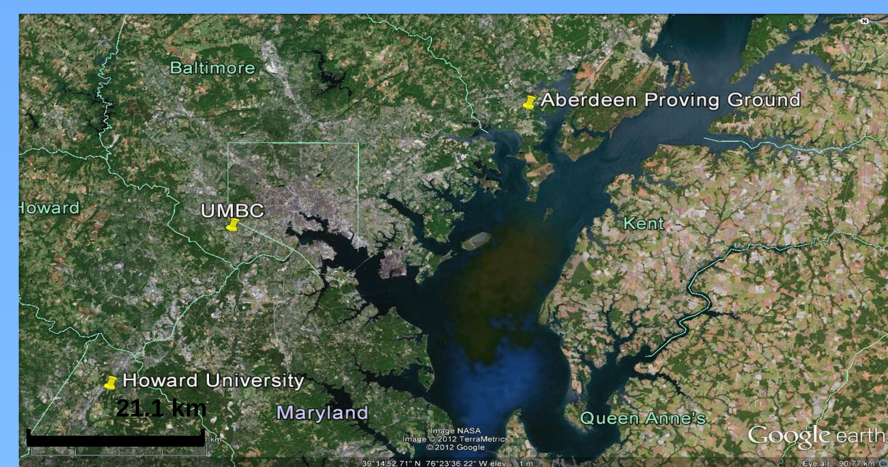

Figure 1: *PBLH multi-instrument intercomparison sites (radiosondes, lidar, ceilometer and wind profiler)*

Covariance Wavelet Transform (CWT)

- Haar function

$$h\left(\frac{z-b}{a}\right)=\begin{cases}-1: & b-\frac{a}{2}\le z\le b\\ 1: & b\le z\le b+\frac{a}{2}\\ 0: & elsewhere,\end{cases}$$

z = altitude (km)
a = spatial extent of the function or "dilation"
b = center of Haar function (km)

- Covariance wavelet transform defined by Gamage and Hagelberg (1993):

$$W_f(a,b)=a^{-1}\int_{z_b}^{z_t} f(z)\, h\left(\frac{z-b}{a}\right)dz$$

z_t and z_b are the top and bottom altitudes in the lidar backscatter profile
$f(z)$ is the lidar backscatter profile as a function of altitude, z
a^{-1} is the normalization factor

- Gradients in lidar backscatter and wind profiler SNR (middle images, Figure 2 and 3, respectively) profiles are correlated to gradients in potential temperature and specific humidity at the top of the PBL (Cohn et al. 2000) (left images, Figure 2 and 3, respectively).
- To determine the PBL height (PBLH), the following algorithm is used (results shown in Figure 2 and 3, right images) (Compton et al. 2012):
  - First step in the algorithm to determine the PBLH is to define the initial conditions: the dilation and center of the Haar function values.
  - The second step is to apply the CWT to the profile for the appropriate dilation and center of the Haar function values by taking the convolution of the profile, $f(z)$, and the Haar function.
  - The sharp gradient decreases in the profile that are of interest are identified by local minimums in the resulting wavelet covariance profile.
  - The smallest local minimum is selected as the PBLH.
  - This process is repeated for each profile in the data set.

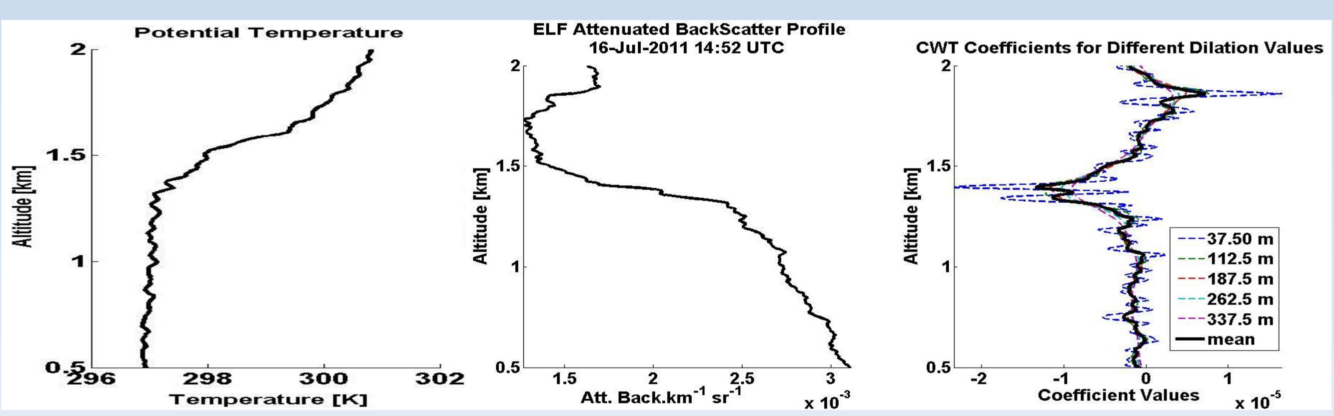

Figure 2: *Potential Temperature, UMBC Lidar Attenuated Backscatter (ELF), and wavelet transforms of the ELF profile for various dilation values.*

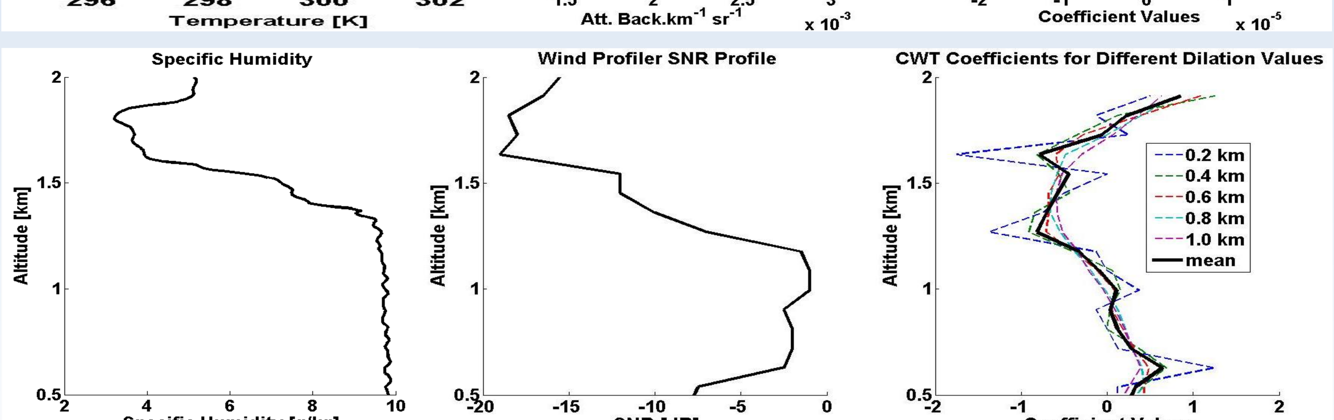

Figure 3: *Specific humidity, Wind profiler SNR, and wavelet transforms of the wind profiler profile for various dilation values*

Comparison of PBLHs from Lidars and Wind Profiler using the CWT with Radiosondes

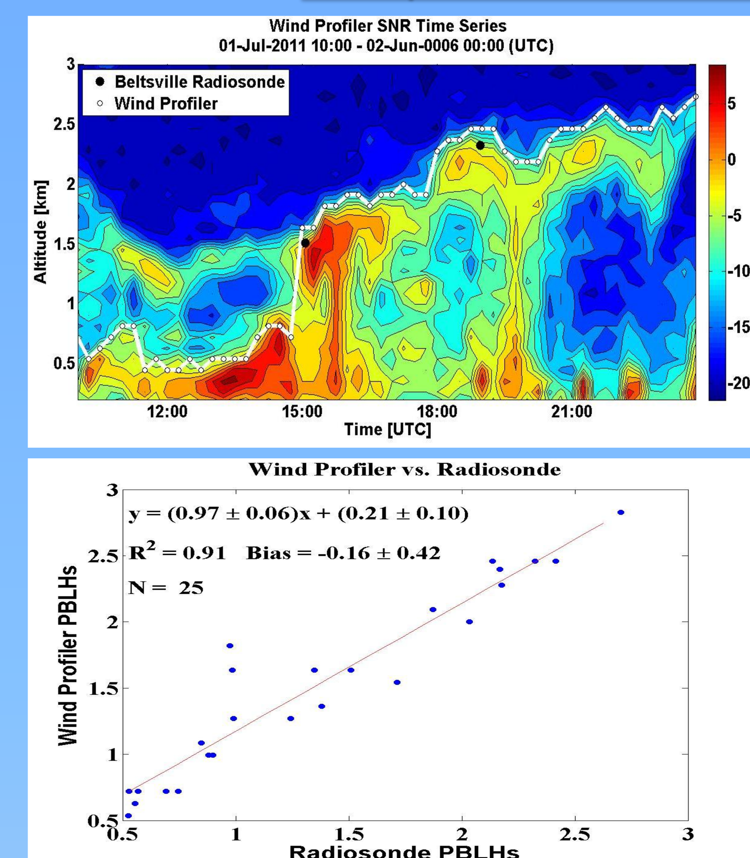

Figure 4: *(Top) Beltsville Wind Profiler SNR Time Series for July 1, 2011 with PBLH's from CWT (white line) and radiosonde (black dots). (Bottom) Linear regression comparing PBLH from the wind profiler using the CWT and radiosonde PBLH.*

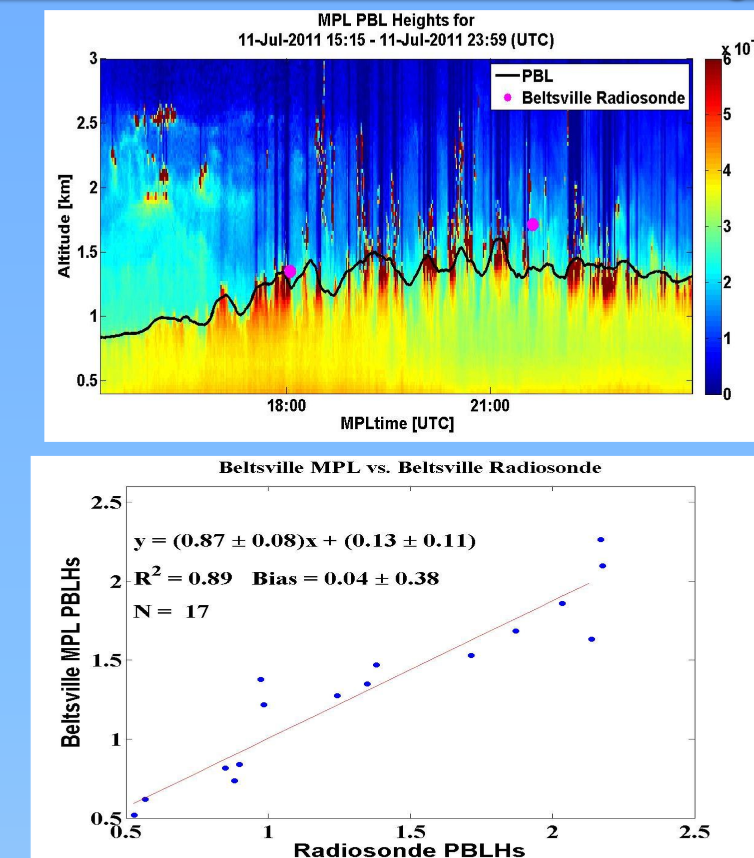

Figure 5: *(Top) Beltsville MPL Attenuated Backscatter Time Series for July 11, 2011 with PBLH from CWT (black line) and radiosonde (magenta dots). (Bottom) Linear regression comparing PBLH from the MPL using the CWT and radiosonde PBLH.*

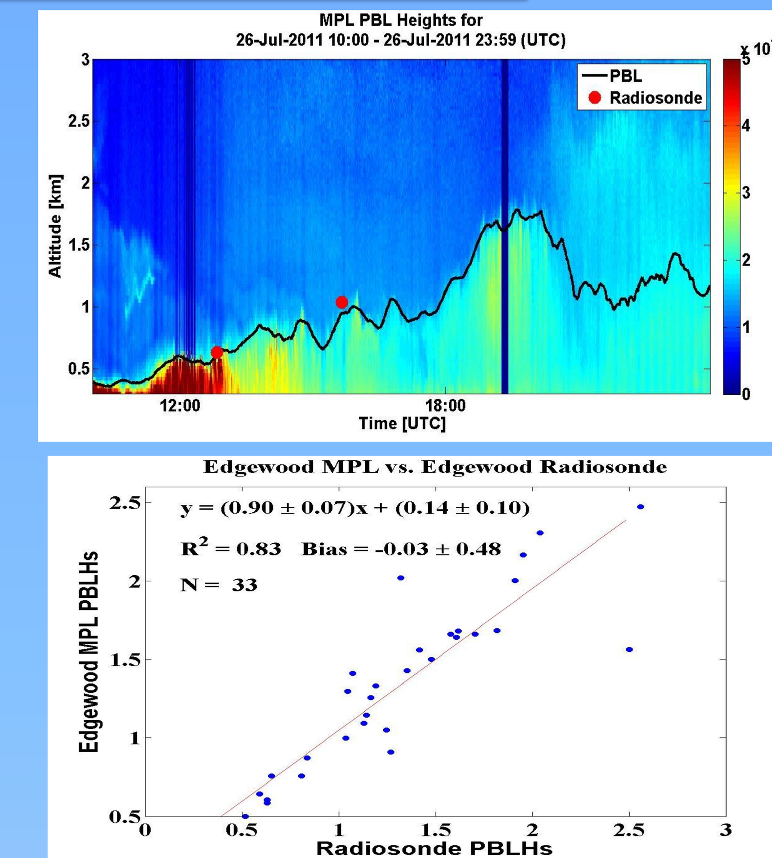

Figure 6: *(Top) Edgewood MPL Attenuated Backscatter Time Series for July 26, 2011 with PBLH from CWT (black line) and radiosonde (magenta dots). (Bottom) Linear regression comparing PBLH from the MPL using the CWT and radiosonde PBLH.*

PBLH Variability Between Locations

- PBLHs at UMBC and Beltsville were similar for the day.
- PBLHs for Edgewood start at similar heights as other instruments in early part of the day, but show a much shallower PBL, greater than 500 meters at times, later in the day.

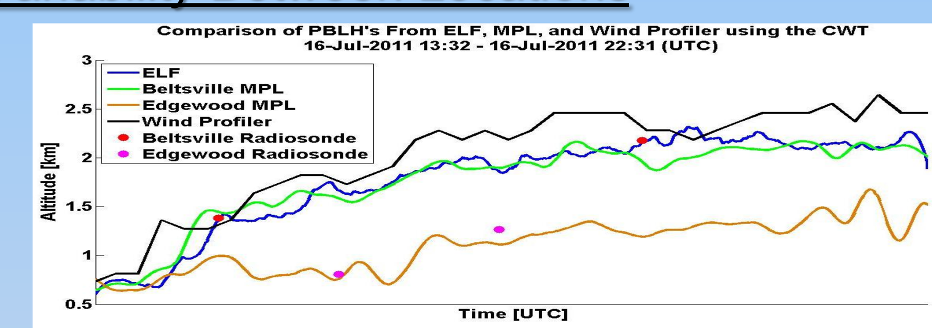

Figure 7: PBLHs from lidars, radiosonde launches, and a wind profiler in various locations across Maryland for July 16, 2011.

Comparison Between MPL and Ceilometer PBLHs

Vaisala CL51 produces three "layers" to be considered candidates as the PBLH. "Layers" are assigned quality index (QI) numbers from 1 to 3, with 3 being the best and being flagged as the PBL. PBLH comparison of the Vaisala CL51 and MPL (Figure 10) was performed using the following method: The "Layer" with QI of 3 was compared against the corresponding MPL PBLH. When there was no "Layer" with a QI of 3, then "Layer" with a QI of 2 was selected. When there were multiple layers with the same QI, the one with the smallest difference against MPL was selected, giving Vaisala the benefit of the doubt. When the ceilometer fails to detect a PBLH and all three "Layers" reported a PBLH of zero meters, the profile was ignored.

Good Comparison Day:
PBLHs for ceilometer and MPL matched up for much of the day. Between 0600 and 1200 UTC, ceilometer selects multiple layers with QI of 3.

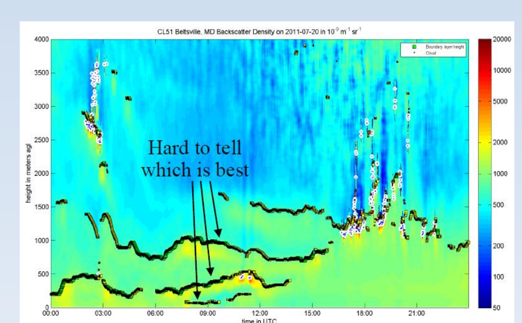

Figure 8a: Ceilometer Time Series

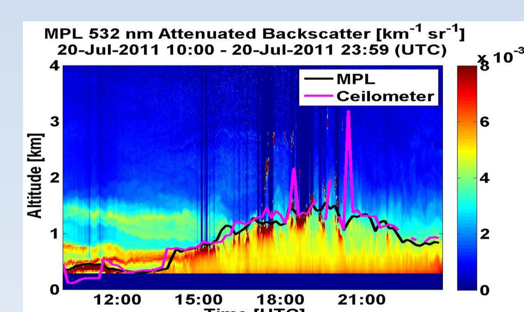

Figure 8b: MPL Time Series

Bad Comparison Day:
Ceilometer does not detect any PBLHs in many profiles after 1200 UTC.

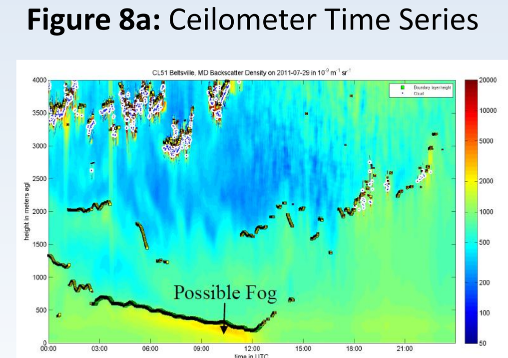

Figure 9a: Ceilometer Time Series

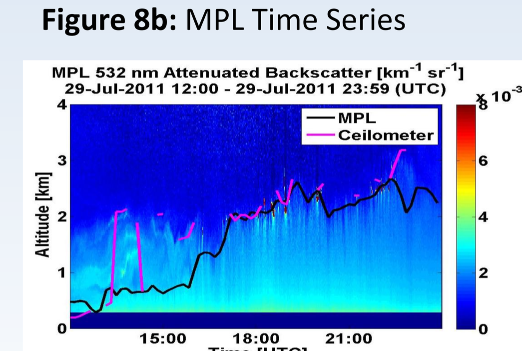

Figure 9b: MPL Time Series

Comparison: Performed for a span of 11 days between July 14 to 29, 2011

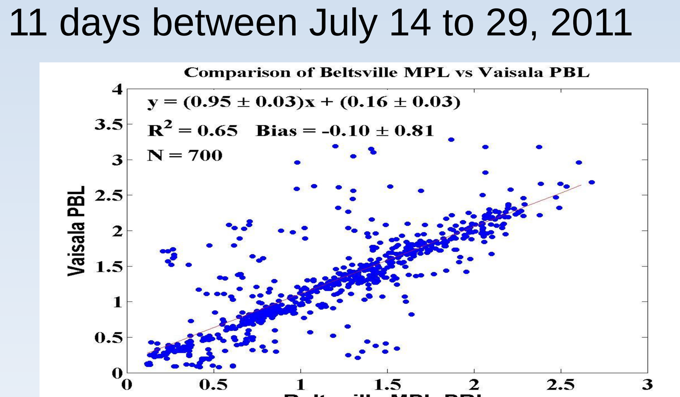

Figure 10: Linear regression comparing PBLHs from MPL and Vaisala Ceilometer

Using the method of comparison described above, out of 809 comparable profiles between the instruments, the ceilometer reported a PBLH of zero meters for 109 of them.

Summary

- The CWT can detect PBLHs from wind profiler and lidars that are in agreement with PBLHs from radiosonde launches.
- PBLHs for UMBC and Beltsville were similar for July 16, 2011.
- PBLHs in Edgewood for the same day were at times greater than 500 meters shallower than PBLH's at UMBC and Beltsville.
- Ceilometer does not always produce a clear PBLH
  - Multiple "layers" are produced
  - Some profiles
    - Do not have a "layer" with QI of 3.
    - Have multiple "layers" with the same QI.
    - Do not have a PBLH, i.e each layer is 0.
  - A Human is need to decide the correct PBL when a clear PBLH is not always produced.
    - The average user may not make the best decision.

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